# Toward a PDF representation of deep convection: Development and evaluation of a parameterization for convective transport of hydrometeors

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## Introduction

An assumed PDF scheme called Cloud Layers Unified By Binormals (**CLUBB**) is employed in global climate models, including ACME and CAM5, to treat turbulence, shallow convection, and stratiform clouds.

When the scheme is extended to **deep convection** and linked to a **prognostic precipitation** scheme (e.g.,MG2), hydrometeor transport becomes important.

The counter gradient vertical transport of precipitation species by infrequent strong updrafts and downdrafts cannot be modeled by the eddy-diffusion approximation.

## Objectives

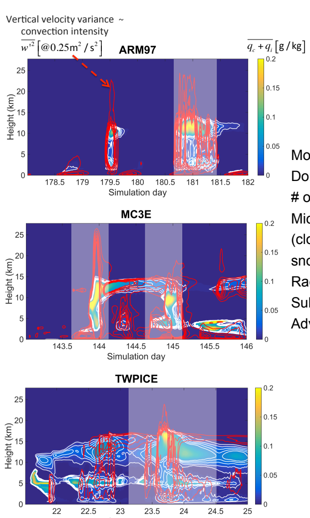
Use information about subgrid-scale variability (i.e., probability density functions (PDFs) for vertical velocity and hydrometeor mixing ratios) to improve the parameterization of turbulent vertical transport in deep convection.

## Off-line testing methodology

Use high-resolution ($\Delta x$=$\Delta y$=250 m) simulations of mid-latitude continental and tropical oceanic convection to provide input, i.e., marginal PDFs, for the parameterization.

Compare parameterized vertical flux profiles with those computed by the cloud-resolving model (CRM) directly.

Four episodes of deep convective from three multiday simulations for mid-latitude continental (ARM97 and MC3E) and tropical oceanic (TWP-ICE) environments.




Model: SAM6.10.3

Domain: 128×128×28 km$^3$

# of levels: 128

Microphysics: 2-moment (cloud liquid and ice, rain, snow, and graupel)

Radiation: RRTM

Subgrid: 1.5-order TKE

Advection: MPDATA

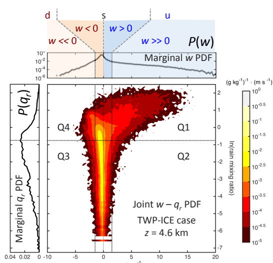
## Method

Previously, we have shown that the correct shape of the vertical flux profile can be obtained by decomposing the flux into contributions from quadrants (Q1-4) of the joint $w$-$q_x$ PDF (*Wong et al.* 2015):

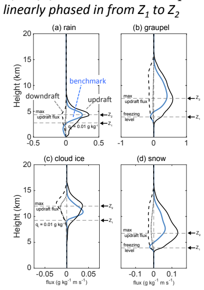
$$\overline{w'q_x'} = \sum_i \sigma_i \overline{w_i'}^* \, \overline{q_{x,i}'}^* \qquad i = \text{Q1, Q2, Q3, Q4} \qquad (1)$$

where $s_i$ is the weight of the quadrant $i$ and $^*$ indicates that the quadrant means are scaled to account for the intra-quadrant correlation of $w$ and $q_x$. However, the joint PDF generally is not known.

Here, we introduce a flux decomposition based on 1-D (marginal) PDFs of $w$ using three regions updraft, downdraft, and stratiform ($i$ = u,d,s)




*Updraft flux is set to 0 below $Z_1$ and linearly phased in from $Z_1$ to $Z_2$*

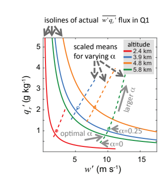



## Scaling

Scaling parameter is closely related to correlation within a quadrant.

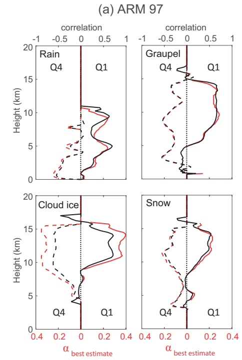
$$\overline{\phi'_i}^* = \frac{\overline{|\phi'_i|^\alpha \phi'_i}}{\overline{|\phi'_i|^\alpha}} = \frac{\int_{\Phi_i} |\phi-\bar{\phi}|^\alpha (\phi-\bar{\phi}) p_i(\phi)\,\mathrm{d}\phi}{\int_{\Phi_i} |\phi-\bar{\phi}|^\alpha p_i(\phi)\,\mathrm{d}\phi}$$

$$p_i(\phi) = \frac{P(\phi)}{\int_{\Phi_i} P(\phi)\,\mathrm{d}\phi}$$




*"Optimal" scaling parameters ~ correlation coefficient in quadrants Q1 and Q4*

(a) ARM 97




Scaling shifts weight to values of larger magnitude;

Optimal scaling parameter: $\alpha \approx 0.25$ for the quadrant decomposition and $\alpha \approx 0.4$ for the 1D $w$ PDF-based decomposition;

Scaling is applied to updrafts and downdrafts. No scaling for stratiform regions.

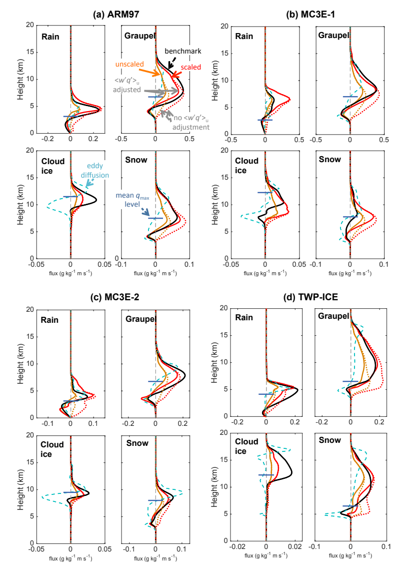
## Results

The new parameterization reproduces the benchmark fluxes well for all four considered cases of deep convection

Decomposition of the fluxes into updraft, downdraft, and stratiform captures the main shape of the net flux profiles

Power-law scaling improves the magnitude of the fluxes

Adjustment of the updraft flux below its maximum improves the net flux profile at lower levels




## Summary

**Vertical fluxes of hydrometeor mixing ratios** by subgrid-scale turbulent motions **are parameterized as a sum of contributions from strong updrafts, strong downdrafts, and quiescent (stratiform) regions**. Mean vertical velocities are computed over corresponding parts of ***w* PDF separated by prescribed thresholds**. Above-the-mean mixing ratios are associated with up- and downdrafts, while below-the-mean mixing ratios are assigned to stratiform regions. A **power-law scaling** is applied to up- and downdraft PDFs **to account for within-the-plume correlation of *w* and $q_x$**, which improves the magnitude of the parameterized fluxes.

The parameterization shows promising results in offline testing for various deep convection cases and is currently being implemented and tested in the CLUBB stand alone model.

**References:** Wong, Ovchinnikov, Wang, 2015: Evaluation of subgrid-scale hydrometeor transport schemes using a high-resolution cloud-resolving model, *JAS*.
Wong and Ovchinnikov, 2016: A PDF-based parameterization of subgrid-scale hydrometeor transport in deep convection, *JAS*. (submitted)

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